Transport of emissions from the 2009 Australian forest fires through the stratosphere: a comparison of MLS observations with FLEXPART model calculations

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Introduction

- The Victoria, Australia fires in February 2009 caused widespread devastation and loss of life
- This event is unique in the six-year Aura Microwave Limb Sounder (MLS) [Waters et al., 2006] record in having a dramatic impact on stratospheric composition
- As shown in Figure 1, MLS observed significant enhancements in CO in the upper troposphere (215 hPa) in the days following the fire peak
- Many similar enhancements have been seen at these altitudes by MLS
- However, the enhancements in the lower stratosphere (100 hPa, Figure 2) are unique in the MLS record
- Similarly, a previously reported [Livesey et al., 2004] enhancement in lower stratospheric CH_3CN was unique in the 1991 – 2000 (intermittent) record from the Upper Atmosphere Research Satellite MLS instrument

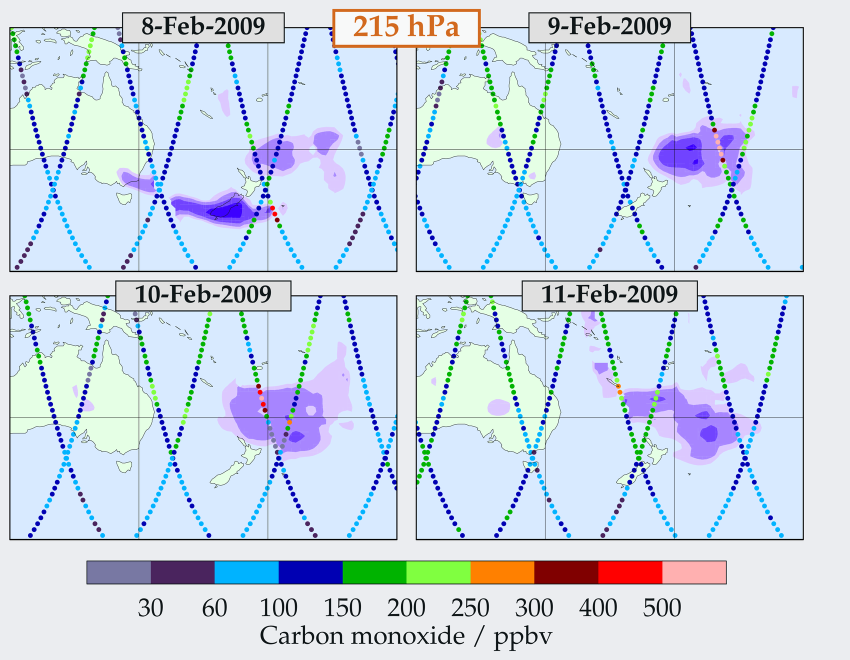


Figure 1: MLS CO observations at 215 hPa (∼10 km) following the 7th February peak in Australian fires. Note that MLS v2.2 CO has a ∼2× high bias at this altitude. Purple shaded contours indicate coincident OMI AI measurements (from ascending/daytime orbits only).

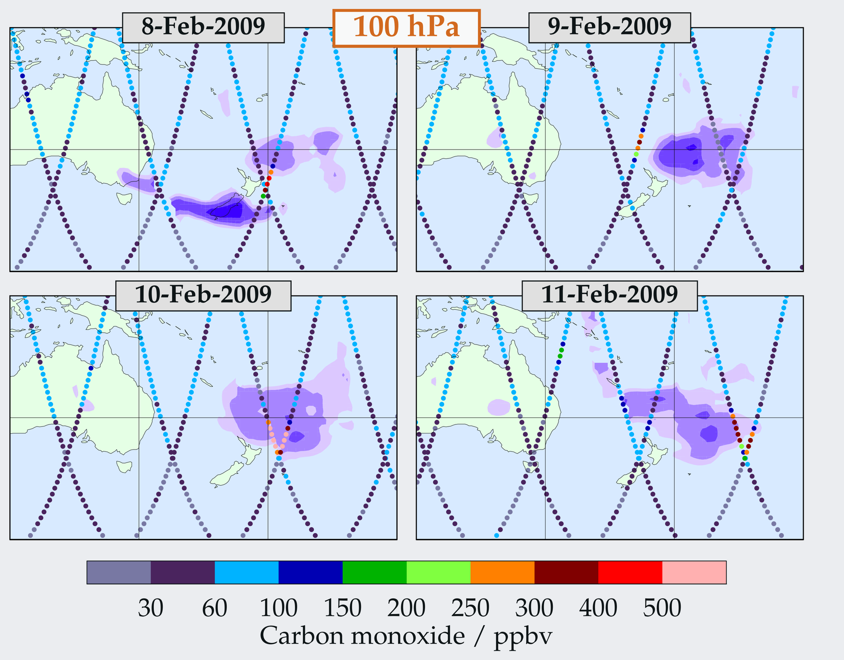


Figure 2: As for figure 1 but for 100 hPa.

Data and model description

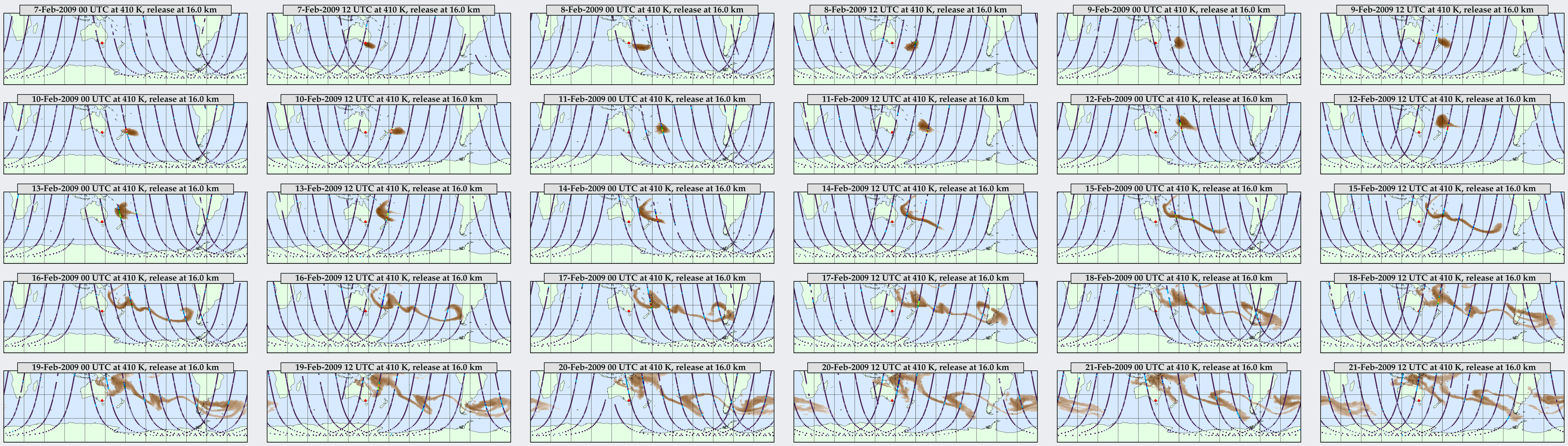
MLS data

- MLS data used here are taken from the production version 2.2 dataset [Livesey et al., 2007]
  - New v3.3 data show similar results
- Profiles are reported on a vertical grid having six surfaces per decade change in pressure (∼2.5 km)
  - Vertical resolution of the CO information is close to this ∼2.5 km grid in the lower stratosphere
  - In the upper troposphere (215 hPa) the CO profiles are measured with ∼5 km vertical resolution
- Individual profiles have a precisions of 10 – 20 ppbv in the lower stratosphere
- The overall accuracy of the MLS CO in this region is estimated as 30% [Pumphrey et al., 2007], and a ∼10 – 20 ppbv low bias is seen in comparison to other instruments
- Profiles have been interpolated onto fixed potential temperature surfaces using the GMAO GEOS version 5.2 analysis fields

FLEXPART model

- Version 8.1 of the FLEXPART [Stohl et al., 2005] Lagrangian chemistry transport model has been run for this period
- The model is driven using 'Version 4' of the NCEP GFS analysis field
- As with the MLS data, model fields are interpolated to fixed potential temperature surfaces using GEOS-5 temperature fields
- 20,000 particles were released during the first 12 hours of 7th February 2009 UT, from 16 – 17 km altitude in the region of the fire (shown by the red diamond in the maps below)

Horizontal advection of the plume



- Figure 3 shows the evolution of the FLEXPART plume at 410 K (∼100 hPa, 16 km) compared to MLS CO observations
- The first few days after plume injection show reasonable agreement
  - For example, 8th-February, 12 UTC
  - However, there are cases (e.g., 9th February, 12 UTC), where MLS observes enhancements not simulated by FLEXPART
- In the ensuing days there are periods of striking agreement
  - For example, 13th February, 0 UTC, 17th February, 0 UTC
- Further simulations with more complex plume releases may improve agreements

Figure 3: Snapshots at 12-hour intervals from the FLEXPART simulation of tracer advection and dispersal at 410 K (brown contours). Colored dots show the MLS observations in a 12 hour window centered on the model snapshot time, interpolated to 410 K. The red diamond indicates the location of the trajectory launches.

Vertical transport of the plume

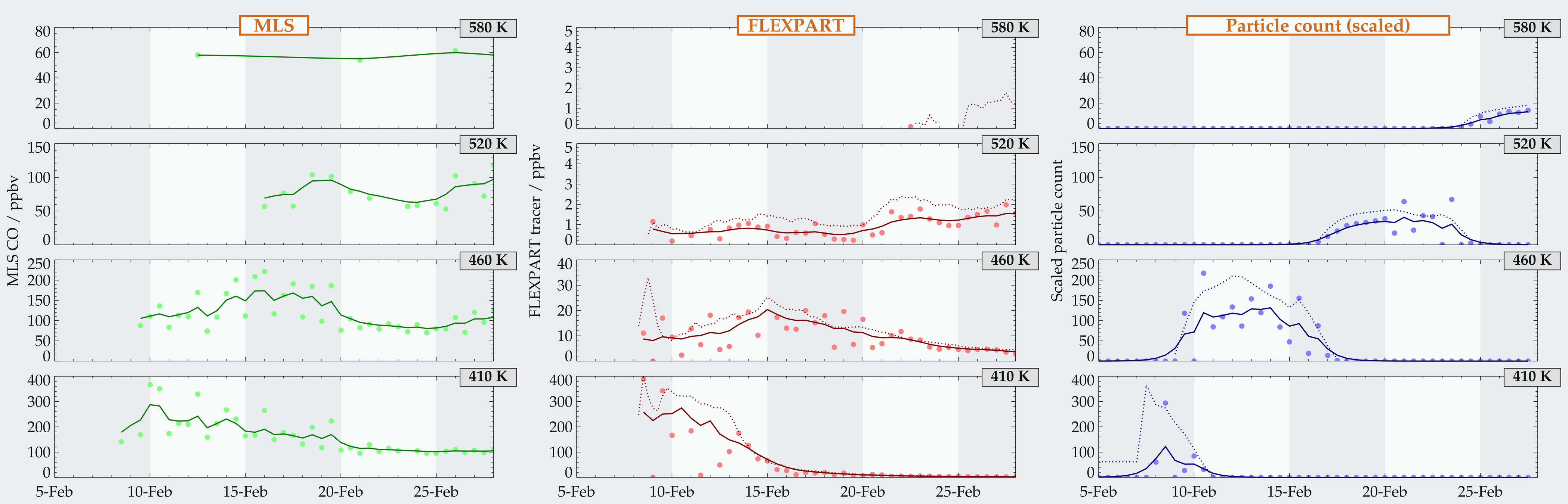


Figure 4: Timeseries of plume evolution for four potential temperature surfaces as measured by MLS (left, green), and depicted by FLEXPART (center, red), and a diabatic trajectory calculation with additional heating (right, blue). For MLS, green points depict the average of all the points, in a 12-hour window, having CO abundance more than four standard deviations greater than the mean. The mean and standard deviation were established from all the February 2009 MLS observations, with $>5\sigma$ spikes iteratively rejected. To reduce the impact of the coarse MLS sampling, a Kalman smoother has then been run through the points, to give the solid green lines. For FLEXPART and the trajectory calculation, the red/blue dashed lines shows the average mixing ratio over all grid cells having non-zero abundances at six hour intervals. To aid comparison with MLS, the FLEXPART/trajectory density fields have been sampled along the MLS track. Red/blue points show the average of the non-zero sampled abundances, while the red/blue solid lines again show the results of Kalman smoothing these points.

- MLS observed the plume rising for several days following its initial injection (left panels in Figure 4)
- By 15th February, abundances as high as 200 ppbv are seen at 460 K (∼68 hPa, ∼17 km)
- Enhanced abundances of 100 ppbv are seen at 520 K (∼46 hPa, ∼19 km) by 19th February
- By contrast, FLEXPART (center panels) shows only small abundances transported above the initial 410 K injection
- The 10 – 20 ppbv noise on individual MLS measurements would make such small enhancements hard to discern
- The timing of the transport is broadly consistent with MLS observations
- A different, GEOS-5-driven, diabatic trajectory calculation (right hand panels), including an additional 8 K/day heating term, shows larger abundances transported
- However, this has incorrect timing, with too rapid a decay at 410 K and early arrival at 460 K

Conclusions and future work

- Pollution from the February 2009 Victoria fires was injected to altitudes, and in abundances, unprecedented in the five-year Aura MLS record
- Abundances as high as 800 ppbv were observed at 100 hPa
- Enhancements were also seen in MLS observations of lower stratospheric CH_3CN and HCN (see other papers in this session)
- FLEXPART simulations show that a plume launched at 16 – 17 km altitude, coincident with enhanced aerosol observed by OMI on 8th February, tracks the observed horizontal advection of CO well
  - Plumes launched 1 – 2 km above and below 16 km exhibit similar behavior (not shown)
- However, FLEXPART fails to reproduce the strong plume ascent observed by MLS:
  - MLS observes significant vertical transport, with abundances transported upwards from initial injection at a rate of 6 – 10 K/day
  - By contrast, FLEXPART shows only small abundances transported significantly above the initial injection region
- The discrepancy could reflect additional heating of soot particles embedded in the plume
- Trajectory calculations including an additional heating term increases the abundances transported, but the timing is unrealistic
- The question remains: *What combination of circumstances resulted in such a strong stratospheric injection from this particular fire?*

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